Asian Dust Above Monterey-2003 (ADAM-2003)

- Science Plan –

Version: 28 March 2003

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Executive Summary

The Asian Dust Above Monterey–2003 (ADAM-2003) project is a surface and airborne observational field study to investigate the properties and effects of the natural and anthropogenic Asian aerosols transported to the west coast of the United States in the springtime.

ADAM-2003 will take place from **April 1-30, 2003** based out of the Monterey, CA region on the central California coast. Funded by the Naval Research Laboratory (NRL) and the Office of Naval Research (ONR), ADAM-2003 is being led and organized by the Naval Research Laboratory-Monterey (NRL-MRY). Participants include scientists from NRL, the Naval Postgraduate School (NPS), NASA, and universities.

ADAM-2003 is a small and focused field project with three **primary objectives**:

1) Characterize the radiative and physical properties of the aged Asian aerosols that reach the west coast of the U.S. in the springtime,
2) Test the predictability skill of the Navy Aerosol Analysis and Prediction System (NAAPS) – a global aerosol forecast model - for simulating trans-Pacific transport of dust and pollutants from East Asia, and
3) Test new, and newly acquired, surface and airborne instrumentation, and test and improve upon observational procedures and strategies in preparation for future field studies.

In addition, **secondary objectives** of ADAM-2003 include:

1) Investigate the effect of aerosols on ocean color and satellite retrievals of ocean color,
2) Quantify the local radiative forcing of the Asian aerosol,
3) Quantify the effects of relative humidity on aerosol absorption,
4) Validate aerosol optical thickness (AOT) retrievals from the MODIS satellite, and
5) Compare with satellite aerosol measurements for validation studies.

To meet these objectives, we will directly measure the radiative, microphysical, and morphological properties of the aged Asian aerosols over the central California coast in the springtime using an emerging surface measurement capability at NRL-MRY, and the NPS Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) Twin Otter research aircraft. The surface measurements will include radiometer (solar and infrared), lidar, sun photometer, and in situ particle measurements. The Twin Otter will be equipped with its suite of in situ aerosol facility instruments, a newly developed stabilized platform hosting radiometric instrumentation, and guest instruments that include a tracking sun photometer (NASA Ames), a cavity ring-down extinction cell (NASA Ames), and a photoacoustic sampler (Desert Research Institute). Satellite measurements (e.g. SeaWifs, MODIS, AVHRR, etc.) will be used to extend our localized measurements to regional scales.

ADAM-2003 Principal Participants:

Mission Scientist:	Anthony Bucholtz (NRL-MRY)
Mission Manager:	Elizabeth A. Reid (NRL-MRY)
Mission Meteorologist:	Annette L. Walker (NRL-MRY)

CIRPAS TWIN OTTER AIRCRAFT:

Lead Flight Scientist:	Anthony Bucholtz (NRL-MRY)
CIRPAS Chief Scientist:	Haflidi Jonsson (NPS-CIRPAS)
Bulk filter sampler:	Jeffrey S. Reid (NRL-MRY), Judy Chow (DRI)
AATS-14 sun photometer:	Beat Schmid, Jens Redemann (NASA-Ames)
Cavity ring-down extinction cell:	Anthony Strawa (NASA-Ames)
Photo-acoustic instrument:	Pat Arnott (DRI)
PHILLS:	Curt Davis, Jeff Bowles (NRL-DC)
DMA:	Don Collins (Texas A&M)

SURFACE SITES:

Surface sites coordinator:	Elizabeth A. Reid (NRL-MRY)

MAARCO (Mobile Atmospheric Aerosol and Radiation Characterization Observatory):

Micro Pulse Lidar:	Piotr Flatau, A. Bucholtz (NRL-MRY) /Marcin Witek (Univ of Warsaw)
Aeronet Sun Photometer:	A. Bucholtz, E. Reid (NRL-MRY)
Solar/IR Radiometers:	A. Bucholtz (NRL-MRY)
Particle Samplers:	J. S. Reid (NRL-MRY)
Weather Station:	E. A. Reid (NRL-MRY)
CSU AMS, OPC, DMA	Kip M. Carrico, Sonia Kreidenweis (CSU)

RADIOSONDES:	E. A. Reid (NRL-MRY)/M. Witek (U. Warsaw)

MIRA (Monterey Institute for Research in Astronomy):

DRUM Sampler:	J. S. Reid, E. A. Reid (NRL-MRY), Tom Cahill (UC-Davis)
MicroTops:	A. Bucholtz (NRL)/Ivan Eberle (MIRA)

R/V Pt. Sur:	Bob Arnone, R. Gould (NRL-SSC)/C. Davis (NRL)

SATELLITES:

AVHRR/GOES AOT:	Arunas P. Kuciauskas (NRL-MRY)
SEAWIFS:	P. Flatau (NRL-MRY), Francisco Chavez (MBARI)
MISR:	Ralph Kahn (JPL)
MODIS:	Jens Redemann (NASA Ames)

AEROSOL MODELING:	D. L. Westphal, A. L. Walker, M. Liu (NRL-MRY)

Scientific Background

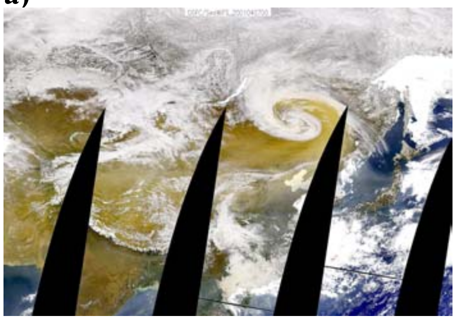
In April of 2001 strong winds over the Takla Makan and Gobi deserts of China and Mongolia generated a massive dust storm (see Fig. 1a). Within days the dust, intertwined with other aerosols and pollution, was transported across China, Korea and Japan and out over the Pacific - degrading visibilities throughout the region (see Fig. 1b). After a week, the plume, now more dispersed and fragmented, had made it to the west coast of the U.S. where it was still visually apparent (see Figs. 1c and 2). By the end of two weeks it had crossed the U.S. and was over the Atlantic.

While this was a particularly strong event it was not unique. In fact, it has recently been learned that such long-range transport of natural and anthropogenic Asian aerosols to North America is actually a common occurrence (e.g. VanCurren and Cahill, 2002). Asia has some of the most productive aerosol source regions on Earth producing particles of widely varying composition and size. Wind-lofted dust from desert regions and particles emitted by human activities produce enormous amounts of aerosols that are lifted into the atmosphere and transported over Korea, Japan, and the North Pacific, frequently reaching the west coast of North America and beyond. Such long-range transport is highly seasonal and variable with the maxima occurring in the spring when meteorological and soil conditions are favorable for generation and transport.

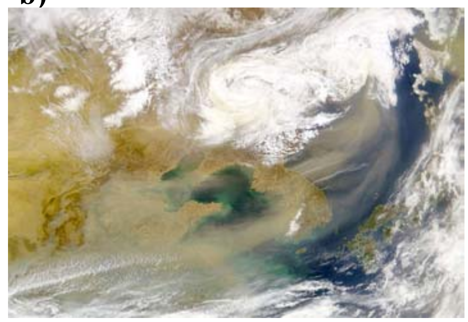
Beyond their obvious role in the degradation of visibility, these Asian aerosol events can have a significant effect on the radiative, dynamical, chemical, and hydrological balance of the atmosphere and surface on local, regional, and global scales. By reflecting sunlight back to space the aerosols can cool the underlying atmosphere and surface and affect surface evaporation rates. By absorbing solar and infrared radiation they can cause localized heating of the atmosphere. Both of these effects can change the heating rate profile, and therefore the dynamics, of the atmosphere with important implications for numerical weather prediction.

In addition, due to their varied composition, size, shape, and amount, the Asian aerosols can adversely affect satellite remote sensing of the atmosphere and surface. Typically, satellite retrievals of such quantities as aerosol amount, ocean color, and sea surface temperature rely on climatology, or arbitrary assumptions, regarding the properties of the aerosols in the atmosphere that may be far from the actual conditions. For example, in some retrievals the aerosols are assumed to be spherical, sulfate particles with a lognormal size distribution. The dust and anthropogenic particles comprising the Asian aerosols are likely to be non-spherical, composed of a variety of minerals, carbon, and soot, with varied size distributions. These differences introduce large errors in the recovered quantities from satellites. With better knowledge of the actual aerosol conditions, and how these conditions evolve with time, satellite remote sensing methods would be improved.

a)



b)



c)

Figure 1: a) SeaWifs image of eastern Asia, April 7, 2001 showing large dust storm being generated over the Gobi and Takla Makan deserts of China. **b)** SeaWifs image from April 8, 2001 showing dust being transported out over the Sea of Japan. **c)** SeaWifs image from April 11, 2001 showing the dust front approaching the west coast of North America

a)

b)

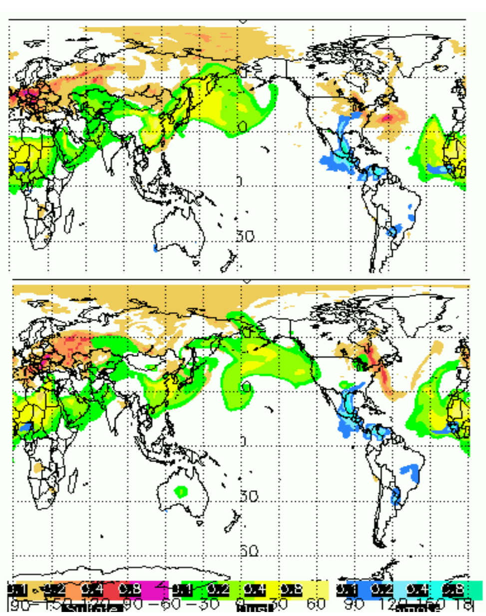


Figure 2: Aerosol optical thickness forecasted by the NAAPS aerosol model for **a)** April 10, 2001, and **b)** April 12, 2001. Greens and yellows represent dust.

Currently, quantitative measurements of the properties and effects of these Asian aerosols are sparse. Particularly lacking is knowledge of how the aerosols evolve with time, and how the aerosols are lifted and transported such long distances without being rained out. Recent experiments in the Eastern Asia/Western Pacific region, such as ACE-Asia (Huebert et al. 2001) and TRACE-P (Jacob et al. 1999) in 2001, have attempted to characterize these aerosols close to their sources. And the ongoing Japanese project, Asian Atmospheric Particulate Environment Change Studies (APEX) will take place March 15-April 15, 2003 and will characterize the aerosol and dust over the Sea of Japan, Korea, and China regions using remote sensing, modeling, and in situ measurements (Nakajima et al., 2003). However, it is known that the radiative, microphysical, and morphological properties of aerosols change during transport. For example, during PRIDE, a field study based in Puerto Rico (Reid et al. 2002), it was found that the optical properties of Saharan dust changed by as much as 50% during transport across the Atlantic Ocean. We would expect similar or even larger changes during transport across the Pacific Ocean - but there are no measurements of aged Asian aerosols in the Western North America region suitable for quantifying the effects of aging.

Also uncertain are the mechanisms of rapid vertical lifting and long-range transport of the dust and anthropogenic aerosol. The lifting is often associated with the warm sector flow ahead of advancing cold fronts, which are frequent during the springtime in eastern Asia, but may also occur behind the cold front. Further to the east, over the Pacific, decoupling of the marine boundary layer from the upper and mid troposphere may contribute to the long-range transport. But understanding of the exact transport mechanisms requires further investigation.

By means of satellite and limited modeling studies, Asian aerosol plumes have recently been observed to travel across the Pacific to the western U.S. and beyond. Recent specialized observations such as the federated sun photometer aerosol network, AERONET, and the emerging lidar network, MPLNet, give us the first global glimpses of the magnitude of the dust plume phenomena but the in-situ measurements along the west coast of North America are still largely missing and modeling efforts need to be improved.

Objectives

ADAM-2003 is a small and focused field project that will address the following basic question:

> What are the properties and effects of the aged Asian aerosols (natural and anthropogenic) that reach the west coast of the U.S. in the springtime?

While a limited number of previous field studies have attempted to characterize the gaseous pollution plume that reaches North America from Asia (e.g. ITCT-2K2; http://www.al.noaa.gov/WWWHD/pubdocs/ITCT/2k2/), ADAM-2003 will be the first field study to specifically look at the aerosols embedded in that plume.

Towards this end, ADAM-2003 has three primary objectives and a handful of lower priority secondary objectives:

Primary Objectives

1. **Characterize the radiative and physical properties of the aged Asian aerosols.** Direct measurements will be made of the radiative, microphysical, and morphological properties of the aged Asian aerosols over the central California coast in the springtime using surface and airborne instrumentation (see appendices A and B for a description of the aircraft and surface instrumentation, respectively). Aircraft measurements will sample the microphysical properties of the aerosols throughout the vertical column from near the surface to 18,000 ft. The aerosol single scattering properties (e.g. single scattering albedo, extinction, scattering, size distributions, etc.) will be characterized. Measurements of the aerosol optical thickness, and the upwelling and downwelling solar and IR flux at multiple levels will yield the vertical profile of the aerosol distribution, and the absorption and heating rates due to the aerosols. Surface measurements will provide longer-term survey measurements of the total column loading (aerosol optical thickness) and the vertical distribution of the atmospheric aerosols (lidar). Satellite data will be used to extend the localized measurements to regional scales.

2. **Test the predictability skill of the Navy Aerosol Analysis and Prediction System (NAAPS) for simulating trans-Pacific transport of dust and pollutants from East Asia.** NAAPS is a global aerosol forecast model (see appendix D for a description of NAAPS). The dust plume morphology along the west coast of the U.S. will be characterized by using satellite (horizontal structure), ground observing networks (vertical structure from lidar), and in-situ aircraft observations (aerosol depth and layering). These measurements will be compared to the output from NAAPS. The layering structure will be investigated using high-resolution models validated against our observational datasets.

3. **Test new, and newly acquired, surface and airborne instrumentation, and test and improve upon observational procedures and strategies in preparation for future field studies.** Most of the instruments proposed for use in this study (e.g. AERONET sun photometer, MPL lidar, the Twin Otter radiometer package, the NASA Ames cavity ring-down cell on the Twin Otter, and the DRI photoacoustic sampler on the Twin Otter) are newly developed and/or newly acquired and will have been on-line for only a short time by April of 2003. ADAM will give us the opportunity to perform a full and rigorous test of these new instruments. For example, we will conduct comparisons of the new aircraft radiometer package with surface instruments by flying multiple altitude profiles over the surface instrumentation. Such profiles will also allow us to test the method of calibrating the MPL with the AERONET sun photometer. Various "closure" studies will be undertaken. For example, comparing aerosol absorption derived from the cavity ring-down instrument with that measured by the

photoacoustic sampler, or comparing vertical profiles of extinction coefficient derived from the tracking sun photometer on the Twin Otter with that measured by the nephelometer and PSAP on the aircraft.

Secondary Objectives

1. **Investigate the effects of aerosols on ocean color and satellite retrievals of ocean color**. Satellites that remotely sense ocean color (e.g. SeaWifs) must first remove the effects of the intervening atmosphere to obtain accurate results. The atmosphere is a major contributor to the measured radiances from these earth-viewing satellites, and aerosols, which vary in time, location, size and composition, are particularly problematic. During ADAM-2003, the tropospheric aerosols will be characterized by surface and airborne measurements. Concurrently, the PHILLS hyperspectral imager on the Twin Otter aircraft, and instruments on the R/V Pt Sur will directly measure ocean color. These combined measurements will be used in ocean color validation studies.

2. **Quantify the local radiative forcing of the Asian aerosol**. Using modeling, satellite, aircraft and ground-based measurements we will derive the radiative forcing of the Asian dust at the surface on regional (central California coast) and local (Monterey) scales.

3. **Quantify the effects of relative humidity on aerosol absorption**. Investigate the change in aerosol absorption with relative humidity.

4. **Validate aerosol optical thickness (AOT) retrievals from the MODIS satellite.** Direct surface and aircraft measurements of AOT will be compared with MODIS derived AOT. The 14-channel NASA Ames Airborne Tracking Sunphotometer (AATS-14) to be flown aboard the Twin-Otter aircraft has been used extensively for that purpose. The ADAM experiment represents the first tropospheric deployment of AATS-14 since a 2.1µm channel for AOT measurements in that region was added to the instrument. Because the two MODIS near-IR channels (1.6 and 2.1µm) are used extensively for the determination of cloud and land surface properties and because the aerosol optical depth data in those channels carries most of the information on the size of larger particles (e.g., mineral dust), validation measurements in that wavelength region are extremely valuable. Typical flight plans would entail transit of the Twin-Otter to a cloud-free area over the dark ocean, and low-level (~30m) horizontal legs for sunphotometer measurements centered around Terra or Aqua overpass times.

5. **Comparisons with satellite aerosol measurements**. Satellites such as GOES, AVHRR, SeaWifs, MODIS, and MISR all provide information on atmospheric aerosols. The fundamental aerosol quantity retrieved from each of these satellites is the aerosol optical thickness. As mentioned above, the intent is to use satellite measurements to extend the localized measurements to regional scales. To do this, the aerosol retrievals from the satellites must be validated. Comparisons of

the satellite measurements with the surface and in situ aircraft measurements will be carried out to aid in this validation.

As with all field studies of natural phenomena, ADAM-2003 will have its challenges. For example, due to the variable nature of the Asian dust storms and the long-range transport involved, there is no guarantee that any significant Asian aerosols will reach the U.S. west coast this year during the timeframe of the study. Also, as mentioned above, ADAM-2003 will be the maiden field study for a significant number of the surface and airborne instruments that will be utilized.

The goals of ADAM-2003, therefore, were purposely kept modest. In particular, ADAM-2003 will not attempt to address the aerosol-cloud interaction problem and **no extensive in-cloud observations are planned**. In the event that no significant Asian aerosol events occur in the region and timeframe of the ADAM study a fraction of the aircraft flights will still be flown to test new instrumentation and to compare with ship and satellite measurements.

Though challenging, the potential returns from ADAM-2003 are compelling. In particular, ADAM-2003 will provide an opportunity to obtain some of the first direct measurements of the properties and effects of the aged Asian aerosols that have been transported the vast distance across the Pacific to North America. In addition, the experience and knowledge gained in ADAM-2003 will prepare observational capabilities and procedures for future field studies.

Resources

The instrument and modeling facilities and capabilities that will be used in ADAM-2003 are described in the appendices.

In general, ADAM-2003 will utilize an emerging surface measurement capability at NRL-MRY, and the NPS Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) Twin Otter research aircraft.

The **surface observations** during ADAM-2003 will consist of a primary surface measurement site located at the Naval Research Laboratory-Monterey (NRL-MRY), and secondary sites at a high-altitude astronomical observatory near Monterey, and a National Science Foundation Research Vessel (R/V Pt Sur) cruising in Monterey Bay. Auxiliary Measurements from state and federal run surface observation networks may also be utilized. The surface measurements will include radiometer (solar and infrared), lidar, sun photometer, in-situ particle sensors, and meteorological measurements. Daily radiosondes will be released from NRL-MRY. (See appendix B for a description of the surface instrumentation.)

The **CIRPAS Twin Otter**, based in Marina, CA will be the sole aircraft used in ADAM-

2003. It will be equipped with its suite of in-situ aerosol facility instruments, a newly developed stabilized platform hosting radiometric instrumentation, and guest instruments that include a tracking sun photometer (NASA Ames), a cavity ring-down extinction cell (NASA Ames), and a photoacoustic sampler (Desert Research Institute). (See appendix A for a description of the aircraft instrumentation.)

The CIRPAS facility will serve as the Operations Center for ADAM-2003 (see below).

Satellite measurements (e.g. SeaWifs, MODIS/MISR, AVHRR, etc.) will be used to extend our localized measurements to regional scales. The NRL Monterey satellite group will provide real time AOT and dust products (AVHRR, GOES). SeaWifs data will be supplied through the Monterey Bay Aquarium Research Institute (MBARI). MISR data will be supplied through the Jet Propulsion Lab. (See appendix C for a description of the satellite measurements).

The **Navy Aerosol Analysis and Prediction System (NAAPS)** – an operational, global tropospheric aerosol model - will be the primary aerosol forecast tool used in ADAM-2003. NAAPS will supply aerosol forecasts of Asian dust events up to 5 days in advance. The post-mission analysis of the measurements from ADAM-2003 will be used to help validate NAAPS. (See appendix D for a description of NAAPS).

Collaborations

ADAM is a small, focused project utilizing local resources of instruments and personnel to minimize costs. However, we have arranged no-cost collaborations to expand on the scientific return from the project:

The Ocean Sciences Division (Code 7333) from **NRL-Stennis** and the Remote Sensing Division (Code 7200) from **NRL-DC** will be conducting a research cruise in Monterey Bay from April 11-24, 2003 on the R/V Pt Sur to study the hyperspectral characteristics of the coastal ocean (D. Johnson, B. Arnone, PIs). ADAM-2003 will benefit this field study by characterizing the atmospheric aerosols above the ship. A group from the Remote Sensing Division at NRL-DC (C. Davis, PI) will operate an ocean viewing hyperspectral imager on the Twin Otter aircraft during ADAM-2003.

NASA Ames Research Center will operate two instruments on the Twin Otter aircraft: the Ames Airborne Tracking Sun photometer (AATS-14) (B. Schmid, PI), and a cavity ring-down extinction cell (A. Strawa, PI). The **Desert Research Institute (DRI)** will operate their photoacoustic sampler instrument on the Twin Otter (P. Arnott, PI). **Texas A&M University** will operate their Differential Mobility Analyzer (DMA) on the Twin Otter (Don Collins, PI). The **University of California-Santa Cruz** will support the optical probes (FSSP, CAPS, and PCASP) on the CIRPAS Twin Otter during ADAM-2003 (P. Chuang). **CIRPAS** will support the remaining facility instruments on the Twin Otter (H. Jonsson, PI). (See appendix A for a description of the Twin Otter instruments).

On the surface, **Colorado State University** (CSU) will operate three instruments in the NRL observation trailer (MAARCO): a DMA (Differential Mobility Analyzer), an APS (Aerodynamic Particle Sizer), and an OPC (Optical Particle Counter) (K. Carrico and S. Kreidenweis, PIs). (See appendix B for a description of the surface instrumentation).

Arunas Kuciauskas from the **NRL-Monterey Satellite group** will provide real time AOT and dust products from AVHRR and GOES. Ralph Kahn from **JPL** will collaborate with ADAM-2003 with respect to the MISR aerosol products. Francisco Chavez from **MBARI** will provide near real-time SeaWifs data. (See appendix C for a description of the satellite measurements.)

For part of the time of ADAM-2003 a major Japanese project, **APEX** (Asian Atmospheric Particle Environmental Change Studies), will take place (March 15 – April 15, 2003). Lead by researchers from the **University of Tokyo** (T. Nakajima, PI) it involves a network of lidar and sunphotometer sites, satellite observations, and aircraft studies of cloud and aerosol properties. In informal discussions, Nakajima has expressed interest in ADAM. We will pursue collaborative efforts with this group. In addition, NRL is working on mesoscale dust source inventories for East and Southwest Asia for use in the COAMPS/Aerosol model. A collaboration with the APEX researchers would provide an opportunity to do validation of the sources and validation of the COAMPS/Aerosol model.

The **NASA Goddard** Geoscience Laser Altimeter System (**GLAS**) was launched on the ICESat spacecraft on January 12, 2003. GLAS is a backscatter lidar that will provide data on the vertical distribution of clouds and aerosols. Validation of the GLAS measurements will begin this spring and the Micro Pulse Lidar measurements from the NRL MAARCO site may be used in these studies. The surface and airborne radiation and aerosol measurements taken during ADAM-2003 may also be useful for GLAS validation.

Logistics and Schedule:

ADAM-2003 will take place from **April 1-30, 2003** based out of the Monterey, CA region on the central California coast (see Fig. E1).

Aircraft measurements will be carried out using the **CIRPAS Twin Otter** research aircraft. (See appendix A for a description of the aircraft measurements). ADAM has reserved **50 flight hours** of the Twin Otter corresponding to approximately **10 flights** (including test flights). The **test flights** will most likely occur in **late March**, with the **research flights** occurring **throughout April 2003** whenever conditions are favorable (that is, when an Asian dust event comes within range of the Twin Otter). All flights will originate from the Marina Municipal Airport in Marina, CA – the home airport of the Twin Otter. (See appendix E for a description of Twin Otter flight plans).

Surface measurements will be carried out from **mid-March through at least mid-May**

at two locations: 1) the Naval Research Laboratory in Monterey, CA and 2) the Bernard M. Oliver Observing Station in the Santa Lucia Mountains southeast of Monterey. (See appendix B for a description of the surface measurements). The intent is to continue a set of core measurements at NRL-MRY indefinitely after ADAM. These core measurements would include aerosol optical thickness, aerosol/cloud vertical structure (lidar measurements), solar and IR flux, and meteorology. Such long-term measurements will allow us to not only observe any Asian dust events but also to monitor and characterize the baseline background conditions in the area.

Shipboard Measurements will be carried out from **April 11-24** on the National Science Foundation (NSF) research vessel **R/V Pt. Sur** sailing out of Moss Landing, CA, approximately 15 miles north of Monterey on the coast of Monterey Bay.. (See appendix B for a description of the shipboard measurements.) The R/V Pt. Sur will cruise in Monterey Bay as part of an ocean color field study.

Base of Operations:

The CIRPAS facility at the Marina Municipal Airport will serve as the base of operations for ADAM-2003. CIRPAS is located approximately 10 miles north of Monterey and the Naval Research Laboratory-Monterey. (See http://web.nps.navy.mil/~cirpas/ for directions to the facility). CIRPAS can supply technical and hardware support for aircraft instrument scientists, it has the cubicle space and internet connections for approximately 6-10 visiting researchers, and a conference room. All ADAM group meetings and briefings will be held in the CIRPAS conference room.

Web Site:

An ADAM-2003 web page will be set-up on the Naval Research Laboratory-Monterey Aerosol homepage (http://www.nrlmry.navy.mil/aerosol/Case_studies/adam/). This web page will show the mission status, the Twin Otter flight schedule, results from the NAAPS aerosol model, aerosol/weather forecasts, relevant satellite imagery, etc. The intent is for this web page to serve as the primary source of information on ADAM-2003.

Timeline:

ADAM-2003 is a unique field study in that there should be plenty of advanced warning of an approaching Asian dust event. This is due to several reasons: 1) Satellite imagery, news reports, and even personal eyewitness accounts from colleagues in Asia, will provide notification of a dust storm in progress in Asia. 2) Any Asian dust storm will take a few days to travel to the west coast of the U.S., and 3) Satellite imagery can be used to track the dust storm across the Pacific.

However, our primary aerosol forecast tool will be NAAPS (Navy Aerosol Analysis and Prediction System) – a global, aerosol forecast model. (See appendix D for a description of NAAPS). NAAPS can provide up to a 5-day forecast of aerosol conditions giving us plenty of advanced warning of when an Asian dust storm is likely to occur and whether it will reach the west coast of the U.S. (and within range of the Twin Otter aircraft).

Given this aerosol forecasting capability a nominal timeline for operations during ADAM-2003 is given in Table 1.

Typically, any Asian dust storm that makes it to the California coast will be dispersed and last for a couple of days (typically 1-4 days), so back-to-back Twin Otter flights are more than likely when dust events occur. Based on sparse data from previous years only 1-4 significant Asian dust events can be expected in April (with 4 being optimistic). Therefore, the envisioned typical operational scenario entails lots of waiting around for a dust event followed by a few days of intense activity involving multiple Twin Otter flights and an increased frequency of surface observations.

Table 1: ADAM timeline

5 days prior to dust event and/or Twin Otter flight	Heads-up notice to all ADAM personnel of approaching dust event and possibility of Twin Otter flight.
2 days prior to dust event and/or Twin Otter flight	- All ADAM personnel notified of high probability of dust event. - Twin Otter flight scheduled. - Twin Otter researchers and crew begin preparations for flight in 48 hours. - MIRA notified and frequency of AOT measurements increased.
1 day prior to dust event and/or Twin Otter flight	**2:00 pm briefing** held at CIRPAS with following agenda: - brief on aerosol and weather conditions - determine ready status of aircraft and instrumentation - make fly/no-fly decision for next day - determine flight plan
Day of dust event and/or Twin Otter flight	**6:30 am briefing** held at CIRPAS with following agenda: - brief on aerosol and weather conditions - determine ready status of aircraft and instrumentation - make final fly/no-fly decision - make final flight plan In addition, radiosondes will be released in the early morning, noon, and late afternoon.
2 hours prior to Twin Otter flight	Twin Otter pilots briefed
1 hour prior to Twin Otter flight	Hands-off Twin Otter

Take-off of Twin Otter	- The Twin Otter must first go to the Monterey County Airport for fueling. This will typically take 1-1.5 hrs. Payload is shut down during refueling. - **Typical flight duration = 5 hours** (not including fueling time at Monterey)

15-30 minutes after landing	**Debrief** held at CIRPAS with following agenda:
	- **pilot debrief**: summary of flight and status of aircraft
	- **science debrief**: summary of flight and status of instruments
	- **planning brief**:
	    - aerosol and weather conditions
	    - make fly/no-fly decision for next day
	    - determine flight plan
	
	If flight planned for next day, timeline will follow the schedule from the point "Day of dust event and/or Twin Otter flight" given above.

Appendix A: Aircraft Instrumentation During ADAM-2003

CIRPAS Twin Otter Aircraft:

The Twin Otter aircraft, owned and operated by the Naval Postgraduate School's (NPS) Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS – http://web.nps.navy.mil/~cirpas/) will be the sole aircraft used in the ADAM field study.

The CIRPAS UV-18A Twin Otter (see Fig. A1), the military version of the De Havilland DHC-6-300, is a robust aircraft well suited for atmospheric science field studies. It can carry a large payload (4500 lbs total in the cabin, nose, and wing pods), has plenty of power for instrumentation (>4500 W), can cruise at a range of speeds (65-165 KIAS), and has the ability to fly from near the surface (≅100 ft) up to 18,000 ft. The maximum flight duration is typically 5 hours (unless additional fuel tanks are added, but this will not be done for ADAM). The Twin Otter carries a crew of two to four: a pilot, co-pilot, and 1-2 (typically, only 1) mission scientists/payload operators.

In addition, CIRPAS has developed its own data acquisition/display system for the Twin Otter that controls, stores, and synchronizes the data from all of the facility sensors onboard. Guest research sensors can tie in to the CIRPAS Twin Otter data system for time synchronization and display of data. A limited bandwidth SATCOM is linked to this data system allowing researchers on the ground to view their data and/or instrument diagnostics in real-time, and to 'chat' with the mission scientist/payload operator on board through the data system.

Figure A1: The CIRPAS Twin Otter Aircraft

The instruments that will be flown on the Twin Otter for ADAM-2003 are listed in Table A1.

In addition to the CIRPAS facility instruments, three guest investigator instruments are being flown on the Twin Otter:

- NASA Ames Research Center (B. Schmid, PI) will operate their Ames Airborne Tracking Sun photometer (AATS-14) on the aircraft. AATS-14 is a 14-wavelength channel instrument that will yield multi-wavelength aerosol optical thickness data and column water vapor.
- NASA Ames Research Center (A. Strawa, PI) will operate their cavity ring-down extinction cell on the aircraft. This instrument measures the aerosol extinction and scattering coefficient. It is a newly developed instrument and ADAM-2003 will be its first field study.
- The Desert Research Institute (DRI) (P. Arnott, PI) will operate their photoacoustic sampler on the aircraft to measure the aerosol absorption coefficient. The airborne version of this instrument is also newly developed and ADAM-2003 will be the first time its made measurements from an aircraft. This instrument will not be ready for the start of ADAM, but will hopefully come onboard sometime in April.

Table A1: **Twin Otter Instrumentation During ADAM**

Instrument	Manufacturer	Measurement	Specs	Notes
Aerosol & Cloud Physics				
PCASP-100	PMS, Inc, DMT Electronics	aerosol size distribution	0.1μm < Dp< 3μm	Facility
FSSP-100	PMS, Inc, DMT Electronics	aerosol size distribution	1μm < Dp < 50μm	Facility
CAPS – Cloud, Aerosol, and Precipitation Spectrometer	DMT, Inc.	aerosol size distribution	0.3μm < Dp < 50μm & 25μm < Dp < 1400 μm	Facility
LWC (part of CAPS)	DMT, Inc.	liquid water content	0-1 g/kg	Facility
PVM-100	Gerber Scientific	liquid water content		under contract
CIP-1D	DMT, Inc.	particle size distribution	25mm < Dp < 1400 mm	Facility
APS – Aerodynamic Particle Sizer (Model 3320)	TSI	particle size distribution	0.5μm < Dp < 30μm	Facility

CPC – Condensation Particle Counter (Model 3010)	TSI		Dp > 10 nm	Facility
Ultrafine Particle Counter (Model 3025)	TSI		Dp > 3 nm	Facility
Cavity Ring-down extinction cell	NASA Ames	aerosol extinction and scattering	675, 1550 nm	NASA Ames instrument
Photoacoustic instrument	Desert Research Institute (DRI)	aerosol absorption	?	DRI instrument (will not be ready for start of ADAM
Bulk filter sampler	DRI	collects particles on filters for later compositional analysis	particles less than ≈ 8 μm	NRL-MRY run instrument
Radiation				
Nephelometer – 3 color (Model 3550/3560)	TSI	Scattering coefficient		Facility
3-color Soot Photometer	Radiance Research	absorption coefficient		Facility – 3-color may not be available for ADAM, in that case, 1-color version used
CM-22 Solar Broadband Radiometers (modified)	Kipp & Zonen (modified by Sandia)	downwelling and upwelling broadband solar flux	0.22-3.6 μm	under contract

CG-4 IR Broadband Radiometers (modified)	Kipp & Zonen (modified by Sandia)	downwelling and upwelling broadband IR flux	4.5-42 μm	under contract
Stabilized Radiometer Platform	Sonoma Design Group	provides stable, level platform for zenith radiometers	maintains stability within +/- 10 deg pitch and roll	under contract
Ames Airborne Tracking 14-channel Sun Photometer – AATS-14	NASA Ames	transmission of direct solar beam at given 14 wavelengths; spectral aerosol optical depth, columnar water vapor, columnar ozone derived	14 channels: 354, 380, 453, 499, 519, 604, 675, 778, 865, 941, 1019, 1241, 1558, 2139 nm	NASA Ames instrument
Ocean PHILLS – Ocean Portable Hyperspectral Imager for Low Light Spectroscopy	Naval Research Laboratory - DC	hyperspectral images of coasts and oceans	400-1000 nm over 6 mm	NRL-DC instrument
Meteorology				
Total Temperature Probe (Model E102AL)	Rosemount	Total temperature	-50C – 50C	Facility
Temperature Probe (Model HMP 243)	Vaisala	Total temperature	-50C – 50C	Facility
Dew point Temperature (Model 137-C3)	Edge Tech	Dew point temperature (chilled mirror device)	-50C – 50C	Facility
Dew point Temperature Probe (Model HMP 243)	Vaisala	Dew point temperature	-50C – 50C	Facility
Static Pressure Transducers (Model 270)	Setra	Barometric pressure, pressure altitude	1200-350 mb,1100-600mb	Facility

Wind-Turbulence (Model 239 – qty 6)	Setra	Six variable capacitance pressure sensors monitor 5-hole Rosemount flow angle sensor – static pressure, dynamic pressure, pressure differentials	0-30" H_2O, -15-15" H_2O	Facility
	NOAA IRGA	Water vapor and Carbon dioxide	H_2O: 2-16g/m3; CO_2: 90-800 g/m^3	Facility
Forward Video		Video pictures out the front of the cockpit for sky conditions	image every 10 secs	Facility
Navigation				
NovAtel	NovAtel Communications, Ltd.	latitude, longitude, altitude, ground speed, track, vertical speed		Facility
TansVector	Trimble	pitch, roll, heading, latitude, longitude, altitude		Facility
C-Migets-II	Systron Donner Inertial Division	position, velocity, attitude, heading, time		Facility
Radar altimeter (Model ALT-50)	Campbell Scientific	altitude	0-500 ft (high resolution); 500-3000 ft (low resolution)	Facility

Appendix B: Surface Instrumentation During ADAM-2003

The surface observations during ADAM-2003 will consist of a primary surface measurement site located at the Naval Research Laboratory-Monterey (NRL-MRY), and secondary sites at a high-altitude astronomical observatory near Monterey, and a National Science Foundation Research Vessel cruising in Monterey Bay. Auxiliary Measurements from state and federal run surface observation networks may also be utilized.

Primary Surface Measurement Site:

MAARCO (Mobile Atmospheric Aerosol and Radiation Characterization Observatory):

The Naval Research Laboratory-Monterey (NRL-MRY) is developing a mobile, surface observation site that will be up and running for ADAM-2003. MAARCO (Fig. B1) is a specially designed, climate-controlled sea-container that will be outfitted with a comprehensive suite of instruments to measure the radiometric and meteorological properties of the atmosphere at the surface, the vertical distribution of aerosols and clouds, and the microphysical and compositional properties of aerosols at the surface.

MAARCO will be the primary surface measurement site during ADAM. Table B1 lists the full complement of MAARCO instruments.

Figure B1: MAARCO on site at NRL-MRY

The jewels in the crown of MAARCO are the Micro Pulse Lidar, which will be part of NASA Goddard's MPL Net (http://mplnet.gsfc.nasa.gov/), a growing worldwide network of aerosol/cloud lidars, and the Cimel Sun Photometer, which will be part of the NASA Goddard AERONET (http://aeronet.gsfc.nasa.gov/), a worldwide network of aerosol sun photometers.

In addition, during ADAM-2003 Colorado State University (CSU) will operate three instruments in MAARCO: a DMA (Differential Mobility Analyzer), an APS (Aerodynamic Particle Sizer), and an OPC (Optical Particle Counter).

MAARCO will be deployed on-site at NRL-MRY (latitude: 36^o 35.503` N, longitude: 121$^o$ 51.236` W, altitude ≅ 170 ft MSL), approximately a half mile from the Pacific coast and Monterey Bay and adjacent to the Monterey County Airport. MAARCO will make continuous measurements beginning in March 2003.

Table B1: MAARCO Instrumentation (unless otherwise noted all instruments are owned and operated by NRL-MRY)

Instrument	Manufacturer	Measurement	Specs	Notes
Radiation				
Sun Photometer	Aeronet-Cimel	Aerosol optical thickness at given wavelengths	340, 380, 440, 500, 675, 870, 1020	
CM-22 Solar Broadband Radiometer	Kipp & Zonen	Total downwelling broadband solar flux	0.2 – 3.6 µm	
Shaded CM-22 Solar Broadband Radiometer	Kipp & Zonen	Diffuse downwelling broadband solar flux	0.2 – 3.6 µm	
CG-4 IR Broadband Radiometer	Kipp & Zonen	Downwelling broadband IR flux	4.5 – 42 µm	
shaded CG-4 IR Broadband Radiometer	Kipp & Zonen	Downwelling broadband IR flux with solar heating of the dome eliminated	4.5 – 42 µm	
CH-1 Normal Incidence Pyrheliometer	Kipp & Zonen	Normal incidence direct solar radiation	0.2 – 4.0 µm	
2AP-GD Solar Tracker	Kipp & Zonen	Provides high accuracy tracking of the sun for the CH-1 Pyrheliometer and solar shading for the CM22 and CG4 radiometers		

Multi-Filter Rotating Shadowband Radiometer (MFRSR)	Yankee Environmental Systems	Total and diffuse solar flux at the given wavelengths from which direct solar flux and optical depth are obtained	?	
Meteorology				
TSI-440A Total Sky Imager	Yankee Environmental Systems	Automated, full sky color images for determining fractional cloud cover and sky conditions	352 x 288 color, 24 bit images. Maximum sampling rate of one image every 30 secs	
ET106 Weather Station: CS500 Air Temperature and RH Sensor, TE525 Rain Gauge, 034A Wind Speed and Direction Sensor, LI200X Solar Radiation Sensor	Campbell Scientific	Air temperature, relative humidity, rainfall, wind speed and direction, and solar radiation	air temperature accuracy: +/- 1.5^{o}C RH accuracy: +/- 3% rainfall accuracy: +/- 1% solar radiation accuracy: +/- 5%	
CS7500 Li-Cor L17500 Open-Path CO_2/H_2O Analyzer	Campbell Scientific	In situ densities of CO_2 and H_2O in turbulent air structures. When used in conjunction with the sonic anemometer measurements the fluxes of CO_2 and H_2O are obtained using the eddy covariance technique	12.5 cm open path, with single pass optics and 1 cm diameter optical beam. Reference filters at 3.95 μm and 2.40 μm. Absorption measured at 4.26 μm (CO_2) and 2.59 μm (H_2O)	

FW05 Type E Fine Wire TC	Campbell Scientific	rapid response temperature probe for eddy correlation		
CSAT3 3-D Sonic Anemometer	Campbell Scientific	Three orthogonal wind components, u_x, u_y, u_z, and the speed of sound	rate: 1-60 Hz resolution: u_x, u_y 1 mm/s rms; u_z 0.5 mm/s rms	
Aerosol				
Micro Pulse Lidar	NASA Goddard	Vertical distribution of aerosols and clouds	523.5 nm, eye-safe system	
3-Wavelength Nephelometer	TSI	Extinction coefficient	450, 550, 700 nm	may have two identical instruments running
Aerodynamic Particle Sizer (APS)	TSI	particle size distribution	0.5µm < Dp < 20µm	NRL-MRY instrument
TEOM Ambient Particulate Monitor	Rupprecht & Patashnick Co., Inc.	total aerosol mass	TSP	
Aerodynamic Particle Sizer (APS)	TSI		0.5µm < Dp < 30µm	CSU instrument
Optical Particle Counter (OPC)	PMS?			CSU instrument
Differential Mobility Analyzer (DMA)	TSI			CSU instrument
TECO Ozone Analyzer	TECO	O_3 concentration		
TECO SO2 Analyzer	TECO	SO_2 concentration		

Radiosondes:

NRL-MRY has acquired 70 Vaisala GPS Radiosondes, Model RS80-15GH (http://www.vaisala.com/), with Kaymont KCI-200N 200 gram balloons for use during ADAM. Vertical profiles of temperature, pressure, wind speed and direction, and relative humidity will be obtained to altitudes greater than 100 mb (≈16 km).

Radiosondes will be released on-site at NRL-MRY on a daily basis throughout April at 12:00 local time (20:00 gmt). On Twin Otter flight days and/or during Asian dust events, additional sondes will be released at 08:00 local time (16:00 gmt) and 16:00 local time (00:00 gmt). Therefore, three sondes will be released on flight days at times approximating pre-flight, mid-flight, and post-flight.

The nearest National Weather Surface standard sounding (http://www.ua.nws.noaa.gov/) is done at Oakland, CA, (latitude: 37° 45'N, longitude: 122° 13'W, elevation: ≅ 5.5 m) at 04:00 local (12:00 gmt) and 16:00 local (00:00 gmt). This is approximately 85 miles north of Monterey.

Secondary Surface Measurement Sites:

MIRA (Monterey Institute for Research in Astronomy):

MIRA (http://www.mira.org/) is a non-profit astronomical institute that operates the Bernard M. Oliver Observing Station (see Fig. B2) – a 36-inch reflecting telescope on top of Chews Ridge in the Los Padres National Forest in the Santa Lucia Mountains (latitude: 36° 18'22.2" N, longitude 121° 33'54.8"W, altitude ≅ 5000 ft), approximately 25 miles southeast of the NRL-MRY MAARCO surface site.

Figure B2: The MIRA Oliver Observing Station (image obtained from the MIRA website)

The Oliver Observing Station has excellent viewing conditions for astronomical observations due to the smooth laminar airflow from the Pacific Ocean. In addition, its high altitude usually puts it above the marine stratus clouds that can frequently occur in the area and allows aerosol sampling in the free troposphere. This combination of traits makes it an attractive site for atmospheric observations.

NRL-MRY intends to make aerosol optical thickness (AOT) measurements at MIRA using a Microtops II (http://www.solar.com/index.htm), hand-held, sun photometer with 5 wavelength channels at 380, 500, 870, 936 and 1020 nm. Ivan Eberle from MIRA will make these measurements.

From late March through early May, 2003, daily AOT measurements will be made at 10:00, 12:00, 14:00, and 16:00 local time (sky conditions permitting). During Twin Otter flight days, and/or Asian dust events, additional AOT measurements will be made throughout the day when possible.

NRL-MRY will also deploy a UC-Davis 8-DRUM (Davis Rotating-drum Universal-size-cut for Monitoring) Impactor Sampler (http://www-chem.ucdavis.edu/groups/kelly/kellyweb_sampling.htm) that continuously collects air samples in 8 aerodynamic size ranges (10.0-5.0, 5.0-2.5, 2.5-1.1, 1.1-0.75, 0.75-0.56, 0.56-0.34, 0.34-0.26, 0.26-0.09 μm). The samples will be analyzed at UC-Davis after ADAM using XRF (X-Ray Fluorescence) analysis to determine the size-resolved aerosol composition.

R/V Pt. Sur:

The Research Vessel Pt. Sur (http://www.mlml.calstate.edu/marinops/) "is owned by the National Science Foundation (NSF), is operated for the Central California Oceanographic Cooperative (CENCAL) by Moss Landing Marine Laboratories, which is located on Monterey Bay". It is part of the UNOLS fleet of research vessels (see Fig. B3).

Figure B3: The R/V Pt. Sur (image obtained from the Moss Landing Marine Laboratories website).

The R/V Pt Sur is approximately 135 ft long and will be used mainly for measuring the hyperspectral characteristics of the coastal ocean. It will cruise in Monterey Bay for two weeks (**April 11-24, 2003**) during ADAM as part of a correlated study on ocean color lead by Donald Johnson (PI) and Robert Arnone (Co-PI) from NRL-Stennis, and Curtis Davis (Co-PI) from NRL-DC.

In addition to a suite of oceanographic instrumentation, regular aerosol optical thickness measurements will be made from deck using a handheld MicroTops Sun Photometer.

Auxiliary Measurements:

The following surface measurement sites are maintained by various state and federal agencies. Though not specifically part of ADAM the data from these sites are publicly available and should be useful in the analysis of Asian dust events.

CIMIS (California Irrigation Management Information System):

Maintained and operated by the California Department of Water Resources, CIMIS (http://www.cimis.water.ca.gov/) consists of a network of over 100 small, autonomous, continuously operating weather stations located throughout California. Figure B4 shows the location of CIMIS sites near Monterey, CA.

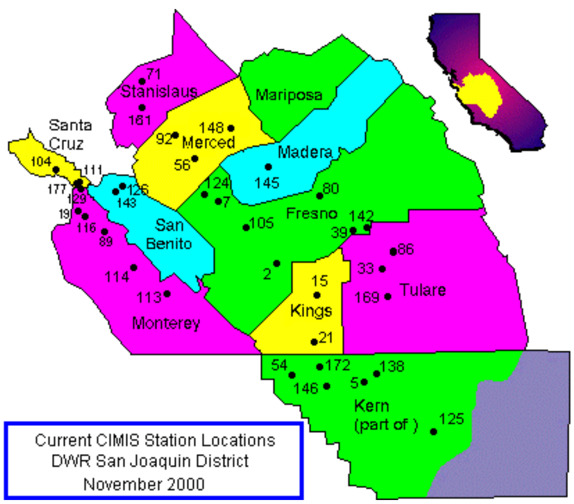


Figure B4: Location of CIMIS sites near Monterey, CA. (image obtained from the CIMIS website)

CIMIS is specifically designed to aid agricultural and private/municipal water users in determining water budgets by measuring evapotranspiration (water loss from evaporation and transfer of water through plants to the air).

Each weather station (see Fig. B5) measures total downwelling solar radiation (using a Li-Cor LI200S Pyranometer), air temperature and relative humidity, wind speed and direction, precipitation, and soil temperature. Readings of all variables are taken every minute and hourly/daily averages computed.

The solar radiation measurements, in particular, may be useful for radiative energy budget studies during ADAM.

Figure B5: CIMIS weather station (image obtained from CIMIS website)

IMPROVE (Interagency Monitoring of Protected Visual Environments):

IMPROVE (http://vista.cira.colostate.edu/improve/) is a network of aerosol/visibility sampling sites located at national parks and wilderness areas throughout the U.S. (see Fig. B6). Governed "by a steering committee composed of representatives from Federal and regional-state organizations", the main goals of IMPROVE are to characterize and monitor aerosol and visibility conditions in these areas.

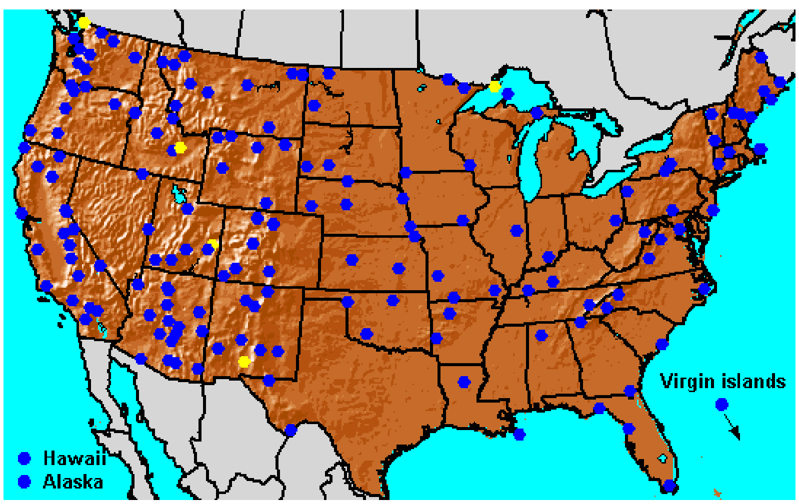


Figure B6: Locations of IMPROVE sites (obtained from IMPROVE website)

Each IMPROVE site measures the concentration and composition of fine aerosols (< 2.5 μm) and PM10 mass (< 10 μm) with certain sites measuring the light extinction coefficient (using a transmissometer) and scattering coefficient (using an integrating nephelometer).

The two sites nearest Monterey, CA are located at Point Reyes National Seashore and Pinnacles National Monument. The Point Reyes site only makes aerosol measurements, while the Pinnacles site only makes the aerosol and transmissometer measurements. Though the measurements are limited these IMPROVE sites, when combined with the MAARCO and MIRA measurements, may be useful in characterizing the Asian aerosols at the surface in the greater Monterey region.

Appendix C: Satellite Measurements During ADAM-2003

There currently exists a fleet of polar and geostationary remote sensing satellites in orbit that derive information on atmospheric aerosols. The intent in ADAM-2003 is to use these satellite measurements to do the following:

- Track the progress of Asian dust events across the Pacific,
- Aid in flight planning for the Twin Otter aircraft, (e.g. determining where to fly),
- Extend our localized surface and airborne observations to regional scales,
- Compare with surface and aircraft measurements for satellite validation studies.

In addition, the standard meteorological satellites will be used for weather prediction and flight planning.

The satellites and products we will utilize in ADAM-2003 are described below.

AVHRR Aerosol Optical Depth:

The Advanced Very High Resolution Radiometer (AVHRR) is a 5-channel (visible to IR), broadband, scanning radiometer (http://edcwww.cr.usgs.gov/glis/hyper/guide/avhrr). This instrument resides onboard both the NOAA-16 and NOAA-17 Polar Orbiting Environmental Satellites (POES) that are in a polar, sun-synchronous orbit at a height of 883 km. During daylight hours each satellite scans similar locations approximately twice per day. NOAA-16 passes over the California coast between 12:30 to 14:00 local time (20:30 to 22:00 GMT), while NOAA-17 passes over the California coast between 10:00 to 12:00 local time (18:00 to 20:00 GMT).

The Naval Postgraduate School (NPS) has developed a method of retrieving the aerosol optical depth (AOD) from the AVHRR visible and near-IR radiance measurements (Durkee, et al., 1999, 1991). Images of the 0.63 μm AOD are generated for maritime environments that are cloud- and sun glint-free (see Fig. C1).

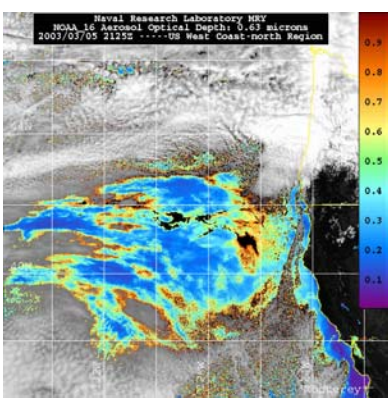


Figure C1: Aerosol optical depth retrieved from the NOAA-16 AVHRR satellite measurements along the northern California coast.

For ADAM-2003, AVHRR AOD images for the west coast of the U.S. will be generated and posted on the NRL Aerosol webpage (http://www.nrlmry.navy.mil/aerosol/) between 12:00 to 13:00 local time (NOAA-17), and between 17:00 to 18:00 local time (NOAA-16). Two images, one covering the coasts of northern California, Oregon, and Washington, and one covering the southern California coast will be posted.

GOES-10 Aerosol Optical Depth:

The Geostationary Operational Environmental Satellite-10 (GOES-10) orbits the Earth in geosynchronous orbit 35,800 km above the equator (http://www.oso.noaa.gov/goes/). GOES-10 (or GOES-West) was launched in 1997 and is located at 135 W longitude with a view of the western half of North America and the Pacific Ocean. The GOES-10 Imager onboard is a five channel (one visible and four infrared) imaging radiometer.

NPS has developed an algorithm for retrieving the aerosol optical depth at 0.65 μm using the visible-channel radiances from the GOES-10 imager (Kuciauskas, 2002). This retrieval uses information gained from the AVHRR AOD processing described above (specifically, aerosol size distribution), to generate half hourly images of the AOD over a maritime environment for cloud- and sun glint-free conditions.

During ADAM-2003, GOES-10 AOD images for the west coast of the U.S. will be generated and posted on the NRL Aerosol webpage (http://www.nrlmry.navy.mil/aerosol/) twice daily following the AVHRR AOD processing. Between 12:00 to 13:00 local time, half hourly images for the first half of the day will be posted. Between 17:00-18:00 local time, half hourly images for the complete day will be posted. Two images matching the AVHRR images in geographical extent will be posted each time, one covering the coasts of northern California, Oregon, and Washington, (see Fig. C1), and one covering the southern California coast.

Though less reliable than AVHRR AOD retrievals, the GOES retrievals will provide a time-series of AOD for analysis and planning purposes.

TOMS Aerosol Index:

The Total Ozone Mapping Spectrometer (TOMS) on the NASA Earth Probe satellite (http://toms.gsfc.nasa.gov/index.html) is a 6-channel backscatter ultraviolet sounder launched in 1996. Earth Probe TOMS is in a circular, sun-synchronous, polar orbit at a height of 740 km. Overpasses occur near local noon.

The NASA Goddard Space Flight Center (GSFC) has developed a technique that retrieves the global distribution of UV-absorbing aerosols from the spectral contrast of the backscattered ultraviolet radiance from two of the UV channels of the TOMS instrument (Torres et al., 1998, 2002). An aerosol index (AI) is derived that gives an indication of the concentration of UV-absorbing aerosols.

The NASA GSFC derived global distribution of AI for the previous day are available once per day at approximately 02:00 PST (10:00 GMT). This data will be used in ADAM to track the progress of Asian dust events across the Pacific, for post-mission model validation, and to extend our localized measurements to regional scales.

SeaWifs:

The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) on board the SeaStar satellite is a multi-spectral optical scanner with 8 wavelength channels from the near-UV to the near-IR (http://seawifs.gsfc.nasa.gov/SEAWIFS.html). SeaWifs was launched in 1997 and is in a sun-synchronous polar orbit at a height of 705 km. Local overpasses occur near local noon.

During ADAM, near real time SeaWifs data will be obtained from the Monterey Bay Aquarium Research Institute (MBARI) (poc: Francisco Chavez). MBARI, located in Moss Landing, CA near Monterey has a SeaWifs receiving station. NRL-MRY will download the SeaWifs data from MBARI and then retrieve aerosol optical thickness (AOT) at 0.680 μm using a 2-channel algorithm.

SeaWifs will pass over Monterey near local noon. The data from MBARI will be available 2-3 hours after the overpass, and NRL-MRY will process the data for AOT within an hour of receiving the datafile from MBARI. Given this schedule, AOT data from SeaWifs for that day should be available by mid to late afternoon.

The SeaWifs AOT will be used in ADAM to track the progress of Asian dust events across the Pacific, for post-mission model validation, and to extend our localized measurements to regional scales.

MISR:

The Multi-angle Imaging SpectroRadiometer (MISR) (http://www-misr.jpl.nasa.gov/) on board the NASA Terra satellite has nine cameras pointed toward Earth at nine look angles ranging from +70 degrees through nadir to –70 degrees in the forward and aft directions along the spacecraft's ground track. Each camera contains four line arrays with blue, green, red, and near-IR filters. MISR produces 36 simultaneous images (9 angles x 4 wavelengths) at up to 275-meter resolution.

MISR on Terra was launched in 1999 and is in a sun-synchronous polar orbit. The MISR swath is approximately 360 to 400 km wide. For a given mid-latitude location an image is obtained every 3-5 days with an overpass time around 10:30 local time.

MISR can obtain estimates of the aerosol amount, particle size, and composition. During ADAM-2003, if the opportunity exists, comparisons will be carried out between surface, airborne, and MISR satellite measurements of aerosols. Airborne measurements from ADAM may also aid in MISR calibration efforts, MISR/MODIS intercomparisons, and validation of MISR aerosol retrievals. For such studies, the Twin Otter would attempt to fly multiple altitude profiles (to characterize the atmospheric aerosols throughout the column) in cloud-free, dark ocean regions corresponding to the time of a Terra/MISR overpass.

Predicted MISR coverage for Monterey, CA is given in Table C1.

MODIS:

The Moderate Resolution Imaging Spectroradiometer (http://modis.gsfc.nasa.gov/) is a 36-channel (0.4 μm to 14.4 μm), cross track scanning spectroradiometer onboard both the NASA Terra (EOS AM) and Aqua (EOS PM) satellites. Terra, launched in December, 1999, and Aqua, launched in May, 2002, are in circular, near-polar, sun-synchronous orbits at an altitude of 705 km. Terra crosses the equator from north to south in the morning (10:30 am) while Aqua crosses the equator from south to north in the afternoon (1:30 pm). MODIS is designed to retrieve information on aerosols, clouds, ocean color, land use, water vapor, ozone, etc.

For ADAM-2003 the specific MODIS products of interest are the retrieved aerosol optical depth and size distribution over the oceans for comparison to our localized measurements, and the RGB images for tracking of the dust across the Pacific.

GOES Vis/IR/water vapor:

The Geostationary Operational Environmental Satellites (GOES-8 and GOES-10) will be used in ADAM as standard meteorological satellites providing near real time visible, IR, and water vapor images for weather prediction and flight planning purposes. GOES visible images are received every 15 minutes (15-45 minute delay), while the IR and water vapor images are received every 30 minutes (15-45 minute delay).

Table C1: Predicted MISR coverage for Monterey, CA March-April, 2003

ID#	Site Name	Path	Date	Orbit#	GMT Day (Df)	X-Track(km)	Lat	Lon
#112	MontereyBay,	Path 45, Block 61	Mar 03, 2003	17059	2003/062/19:07:00	169.0 E	36.800	-121.900
#112	MontereyBay,	Path 43, Block 61	Mar 05, 2003	17088	2003/064/18:55:00	100.0 W	36.800	-121.900
#112	MontereyBay,	Path 44, Block 61	Mar 12, 2003	17190	2003/071/19:00:00	29.0 E	36.800	-121.900
#112	MontereyBay,	Path 45, Block 61	Mar 19, 2003	17292	2003/078/19:07:00	169.0 E	36.800	-121.900
#112	MontereyBay,	Path 43, Block 61	Mar 21, 2003	17321	2003/080/18:55:00	100.0 W	36.800	-121.900
#112	MontereyBay,	Path 44, Block 61	Mar 28, 2003	17423	2003/087/19:00:00	29.0 E	36.800	-121.900
#112	MontereyBay,	Path 45, Block 61	Apr 04, 2003	17525	2003/094/19:07:00	169.0 E	36.800	-121.900
#112	MontereyBay,	Path 43, Block 61	Apr 06, 2003	17554	2003/096/18:55:00	100.0 W	36.800	-121.900
#112	MontereyBay,	Path 44, Block 61	Apr 13, 2003	17656	2003/103/19:00:00	29.0 E	36.800	-121.900
#112	MontereyBay,	Path 45, Block 61	Apr 20, 2003	17758	2003/110/19:07:00	169.0 E	36.800	-121.900
#112	MontereyBay,	Path 43, Block 61	Apr 22, 2003	17787	2003/112/18:55:00	100.0 W	36.800	-121.900
#112	MontereyBay,	Path 44, Block 61	Apr 29, 2003	17889	2003/119/19:00:00	29.0 E	36.800	-121.900
#112	MontereyBay,	Path 45, Block 61	May 06, 2003	17991	2003/126/19:07:00	169.0 E	36.800	-121.900
#112	MontereyBay,	Path 43, Block 61	May 08, 2003	18020	2003/128/18:55:00	100.0 W	36.800	-121.900
#112	MontereyBay,	Path 44, Block 61	May 15, 2003	18122	2003/135/19:00:00	29.0 E	36.800	-121.900
#112	MontereyBay,	Path 45, Block 61	May 22, 2003	18224	2003/142/19:07:00	169.0 E	36.800	-121.900
#112	MontereyBay,	Path 43, Block 61	May 24, 2003	18253	2003/144/18:55:00	100.0 W	36.800	-121.900
#112	MontereyBay,	Path 44, Block 61	May 31, 2003	18355	2003/151/19:00:00	29.0 E	36.800	-121.900

Times are shown for the start of Local Mode acquisition for Df camera, duration of Local Mode is 7:35 minutes, therefore overpass of An camera is 3:47 minutes after Df. Extents and view angles are with respect to the latest orbit prediction, not the block center. The east/west designation is the direction of the Local Mode site from the ground track.

Appendix D: Aerosol Modeling During ADAM

NAAPS (Navy Aerosol Analysis and Prediction System):

Douglas L. Westphal at the Naval Research Laboratory-Monterey (NRL-MRY) has developed a global tropospheric aerosol model that generates near real-time forecasts of aerosol conditions worldwide. NAAPS (http://www.nrlmry.navy.mil/aerosol/) uses meteorological fields from NOGAPS (Navy Operational Global Atmospheric Prediction System) – a global weather model - to generate global dust, sulfate, and smoke forecasts on a 1 X 1 degree grid at 6-hour intervals out to 120-hours. NAAPS provides spatial (vertical and horizontal) and temporal mass concentrations of each aerosol type. When multiplied by an estimated mass extinction efficiency the aerosol optical thickness for each species can be obtained. A more detailed description of the model is given below.

During ADAM, NAAPS will provide up to a 5-day forecast of the likelihood, timing, magnitude, and distribution (vertical and horizontal) of Asian dust events that reach the west coast of the U.S., specifically focused on the region within range of the Twin Otter aircraft.

Of course, as the time to an Asian dust event gets shorter the forecasts will improve. Therefore, using NAAPS and satellite imagery we anticipate having at least 48 hours notice of a possible Twin Otter flight day.

Detailed Model Description:
The Navy Aerosol Analysis and Prediction System (NAAPS) is a multi-specie, three-dimensional, global transport model derived from the hemispheric SO_2 and sulfate model of Christensen (1997). Details of the model are given in that reference, and only an overview is presented here, with emphasis on modifications made to the original model. The Navy's Operational Global Analysis and Prediction System (NOGAPS) weather forecast model provides five-day forecasted dynamical fields to NAAPS at 6-hour intervals. These fields are the topography, sea ice, surface stress, surface heat flux, surface moisture flux, surface temperature, surface wetness, snow cover, stratiform precipitation, convective precipitation, lifting condensation level, cumulus fractional coverage, cumulus cloud height, surface pressure, three components of the wind field, temperature field, and relative humidity. Transport is calculated using a 3-d semi-Lagrangian scheme (Staniforth and Cote, 1991) with departure points calculated using the method of Ritchie (1987). Modifications have been made to the interpolation of wind and concentration fields across the poles and the interpolation method was changed from a 3rd order Lagrange to 5th order Lagrange. Horizontal and vertical diffusion are calculated with a finite element scheme. The diffusion coefficients are determined from the input NOGAPS data, based on Monin-Obukhov similarity theory. The horizontal diffusion coefficient is set to a constant. The moisture fields are used in an inverse precipitation scheme to diagnose vertical profiles of cloud water and precipitation rate

consistent with the input precipitation rates. These profiles are used to calculate the wet removal and reaction rates of the various species. The dry deposition velocity is based on the resistance method (Voldner et al., 1986; Walcek et al., 1986' and Slinn and Slinn, 1980), where the deposition velocity depends on the turbulence of surface layer and surface type (ocean, grassland, etc.).

The **sulfur dioxide emission** is based on the GEIA inventory, version 1A, for the year 1985 with a seasonal variation and two-level vertical distribution (Benkovitz, 1996). Natural emissions of DMS are immediately converted to 95% sulfur dioxide and 5% sulfate. The gas-phase chemistry is described by a simple linear reaction rate, which depends on the time of year and latitude.

Dust emission occurs whenever the friction velocity exceeds a threshold value and the surface moisture is less than 0.3. The threshold friction velocity is set to infinity except in known dust-emission areas where it is 60 cm/s (Westphal et al, 1988). These areas are currently defined as areas covered by the eight erodible land-use types used in the USGS Land Cover Characteristics Database (ref).

Smoke has recently been added to NAAPS. In this preliminary implementation, smoke emissions are based on the remote sensing of fires by GOES Wildfire ABBA. The ABBA product is available in near real-time at half-hour intervals each day for the western hemisphere. ABBA reports fire size for some fires, but cannot determine fire size for others. For the latter we assign a fire size of 0.05 km^2. The emission rate is chosen based on land use type and SCAR-B data [*Ferek et al*, 1998; *Guild et al*, 1998]. The current day's emissions are used for each of the five forecast days. For the rest of the world, we use the IONIA product. It is available only once daily with no information on fire size or intensity. We use the same fire locations for the entire day and arbitrarily set the fire size to 0.02, 0.1, 0.2, and 0.1 km^2 at 0000, 0600, 1200, and 1800 UTC. An emission rate of 1e-5 g m^{-2} s^{-1} is also used. The MODIS fire product will be used when it becomes available.

Appendix E: Twin Otter Flight Plans

The CIRPAS Twin Otter can cruise at a range of speeds (65-165 KIAS), and has the ability to fly from near the surface (≅100 ft) up to near 18,000 ft. The maximum flight duration is typically 5 hours (unless additional fuel tanks are added, but this will not be done for ADAM).

The ADAM field study has reserved **50 flight hours** of the Twin Otter. Assuming **5 hours per research flight**, and 1-2 test flights of approximately 2.5 hours maximum each, ADAM should have the capability of making at least 9 research flights.

The test flights will most likely occur in late March, with the remaining 9 flights occurring throughout April 2003 whenever conditions are favorable (that is, when an Asian dust event comes within range of the Twin Otter). Ideally, only one test flight will be required and/or the test flights will occur during Asian dust events, increasing the number of research flights.

All of the flights will originate from the Marina Municipal Airport (latitude=36.682 N, longitude=121.762W, elevation= 134 ft) in Marina, CA – the home airport of the Twin Otter. Marina is located approximately 10 miles north of Monterey, and the airport is approximately 2 miles off the coast of central California.

Due to the lack of fueling facilities at the Marina Airport, the Twin Otter will first need to fly the short distance to the Monterey County Airport for fueling before each flight. Research flights will then continue from the Monterey Airport. Since the MAARCO surface site is located adjacent to the Monterey Airport, this will afford numerous opportunities for vertical profiles over MAARCO as the Twin Otter lands or departs from the airport.

Due to the typical widespread nature of any Asian dust events that make it to the west coast of California it is hoped that most flights will occur in the general area of Monterey Bay with minimal transit time required. However, this may not always be possible. Therefore, allowing for an "on station" time of approximately 2 hours, the Twin Otter has a maximum of 1.5 hours available for transit each way. At a transit speed of 140 kts, the maximum range of the Twin Otter for a research flight is therefore approximately 210 nautical miles. This range allows the aircraft to reach as far north along the California coast to just north of Ft. Bragg, to as far south as northern Los Angeles, and up to 210 nautical miles out over the ocean west of Monterey (with some limitations due to airspace Warning Areas). (See Fig. E1)

The range of the Twin Otter could be greatly extended by including a refueling stop along the transit route. In the extreme case, the Twin Otter could fly its maximum range (approximately 700 miles, i.e. a 5 hour flight), refuel, conduct a full 5 hour research flight, refuel again, and then return home. This would allow the Twin Otter to reach as far north as Washington State, for example, or basically anywhere along the west coast of the U.S. However, such a scenario would eat up at least 15 hours of research flight time and require one to two overnight stays for the Twin Otter crew. Therefore, such a flight plan will probably only be used near the end of the field study if enough flight hours are available and the nature of the dust event warrants it.

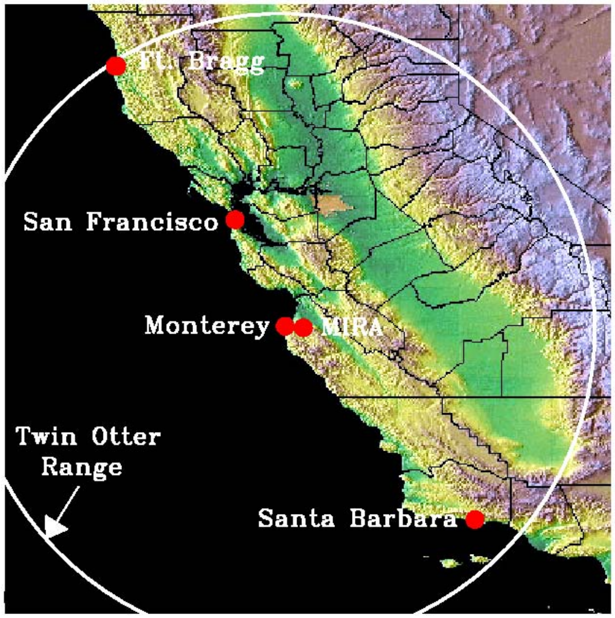


Figure E1: The approximate range of the Twin Otter aircraft assuming 2 hours 'on station', 1.5 hours transit time each way, and no refueling (Image by K. Richardson).

Below are described a series of flight plans for the Twin Otter during ADAM-2003. Flight Plan 3, "Asian Aerosol Characterization", is the primary flight plan. Since some of the other plans will take-up only a fraction of the Twin Otter's 5-hour flight duration, two or more of these flight plans may be combined and carried out during one research flight.

Since the aerosol, cloud and meteorological conditions will be highly variable during ADAM-2003, the flight plans described here are meant to serve as a guide. Actual flight plans will be designed to fit the situation.

FLIGHT PLAN 1: TEST FLIGHT

Objectives: General checkout and test of the Twin Otter payload during flight.

Requirements: No specific requirements. Ideally, we would like to sample some significant aerosols to test the particle probes.

Strategy: The strategy here is simple. Climb to an initial altitude and check all systems in flight. Then climb to a high altitude and remain there for a period of time to check all systems in a cold, low pressure environment.

Total Time: ≅ 2.5 hours

1) Test flight:

Instructions:

- Flight Plan 2, "Test of the Stabilized Radiometer Platform", could serve as this test flight.

Procedure:

- Take-off from Monterey
- Climb to 5000 ft
- Find and sample some aerosols (perhaps from Moss Landing power plant)
- Climb to 17,500 ft
- Remain at altitude for ≈20 mins
- Descend
- Land at Marina

FLIGHT PLAN 2: TEST OF STABILIZED RADIOMETER PLATFORM

Objectives: Test and characterize the newly developed stabilized radiometer platform.

Requirements: Clear skies above the aircraft.

Strategy: ADAM-2003 will be the maiden voyage for the newly developed stabilized radiometer platform mounted on top of the CIRPAS Twin Otter. The requirements call for the platform to remain level for a range of +/- 10 degrees in aircraft pitch and/or roll, and to correct for aircraft vibration and moderate turbulence. For pitch/roll outside the +/- 10 degree range the platform will lock and follow the movements of the aircraft, but once the pitch/roll is within range again, the platform should resume active stabilizing.

To fully test and characterize the platform the following 10 flight maneuvers will be performed (in no particular order):

Total Time: 2.75 hours

1) **Box: (Time: ≅40 mins; Goal: Determine orientation offsets of radiometers)**

   Instructions:
   - Perform at high altitude
   - All legs are straight and level (SL)
   - Keep orientation with respect to sun instead of flying perfect box pattern

   Procedure:
   - 10 min SL leg directly into sun
   - Turn left 90 degrees
   - 10 min SL leg with sun 90 degrees to starboard
   - Turn left 90 degrees
   - 10 min SL leg directly away from sun
   - Turn left 90 degrees
   - 10 min SL leg with sun 90 degrees to port

2) **Wiggles: (Time: ≅10 mins; Goal: Simulate turbulence)**

   Instructions:
   - Perform at high altitude

   Procedure:
   - Vary yaw +/- 20 degrees; 0 degree pitch and roll; directly into sun
   - Vary pitch +/- 10 degrees; 0 degree roll; directly into sun
   - Vary roll +/- 10 degrees; 0 degree pitch, sun at 90 degrees to side

3) **Steep turns: (Time: ≅15 mins; Goal: Test platform recovery)**

   Instructions:
   - Altitude at discretion of pilots

   Procedure:

- Left 360 degree turn; 45-60 degree bank
- Straight and level flight for at least 5 minutes
- Right 360 degree turn; 45-60 degree bank
- Straight and level flight for at least 5 minutes

4) High altitude: (Time: ≅20-40 mins; Goal: Low temperature and pressure test)

Instructions:
- Altitude = 17,500 ft
- Could be combined with other maneuvers
- Ideal time to perform Box maneuver

Procedure:
- Remain at altitude for at least 20 min

5) Low altitude: (Time: ≅10 mins; Goal: High pressure, turbulent test)

Instructions:
- Altitude = 100 ft

Procedure:
- Remain at altitude for at least 10 min

6) Spiral ascent: (Time: ≅10 mins; Goal: Determine max spiral ascent rate and minimum spiral diameter)

Instructions:

Procedure:
- Climb in spiral; pitch < 10 degrees, roll < 10 degrees; max ascent rate
- Straight and level flight at top of spiral

7) Spiral descent: (Time: ≅10 mins; Goal: Determine minimum spiral diameter)

Instructions:

Procedure:
- Descend in spiral; pitch > -10 degrees, roll < 10 degrees;
- Vary descent rate from 500-1500 fpm

8) Flat ascent: (Time: ≅10 mins; Goal: Determine max ascent rate)

Instructions:

Procedure:
- Straight climb; pitch < 10 degrees, roll = 0 degrees

9) Flat descent: (Time: ≅10 mins; Goal: Performance during descent)

Instructions:

Procedure:
- Straight descent; pitch > -10 degrees, roll = 0 degrees
- Vary descent from 500-1500 fpm

10) Turbulence: (Time: ≅10 mins; Goal: Performance during turbulence)

Instructions:
- Any altitude

- Keep pitch/roll within +/- 10 degrees

Procedure:

- Straight and level flight in real mild to moderate turbulence

FLIGHT PLAN 3: ASIAN AEROSOL CHARACTERIZATION

Objectives: To characterize the radiative and microphysical properties of the Asian aerosols. To conduct radiative/microphysical closure studies.

Requirements: An Asian aerosol event. Clear skies would be ideal, but this could be done in high or low cloud, or partly cloudy conditions (radiometer data in these conditions would be problematic, but the in situ data would still be of value). Clear ocean below would also be ideal.

Strategy: The strategy here is straightforward: Perform vertical ascents or descents to define the location of the aerosol layers and to obtain: a) AOT/extinction profiles from the sun photometer; b) extinction, scattering, and absorption profiles from the various in situ samplers; and c) solar and IR radiative flux profiles from the radiometers (see Fig E2).

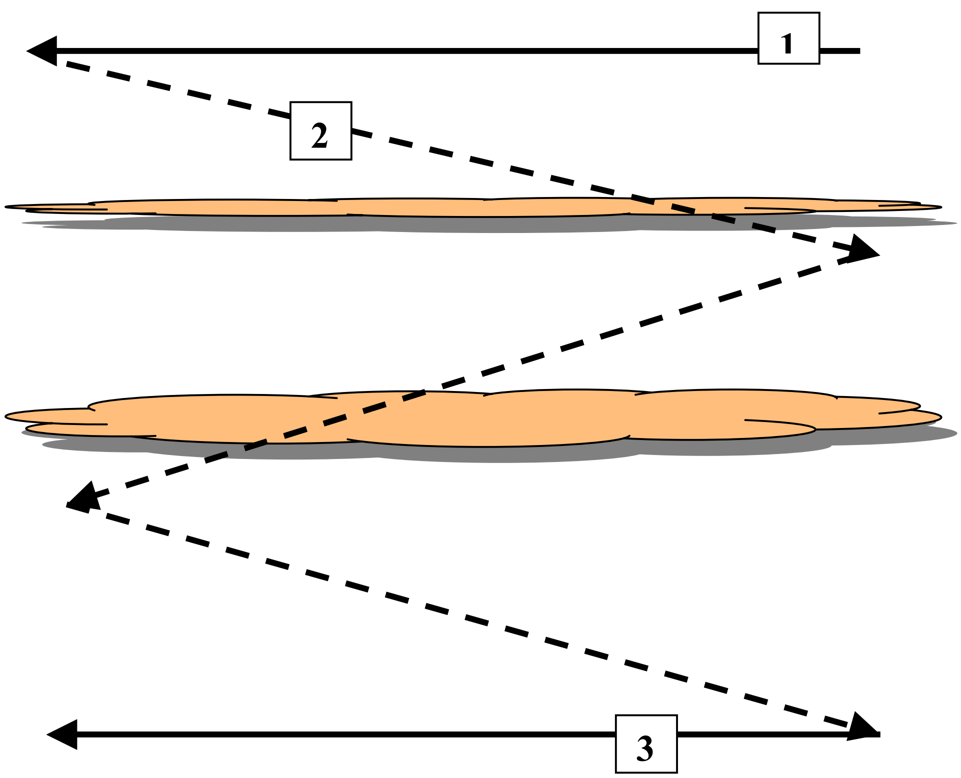


Figure E2: Flight profile for defining vertical location of aerosol layers, 1) straight and level high altitude radiation leg above layers, **2)** level escalator descent to surface (pitch ≥-10 deg; descent rate≤ 500 fpm) remaining underneath radiation leg endpoints, number of sections depends on initial altitude, **3)** low altitude (100 ft) straight and level radiation leg below layers.

Once the locations of the aerosol layers are determined, fly level legs above and below the layers for radiative flux measurements, and inside the layers for in situ sampling.

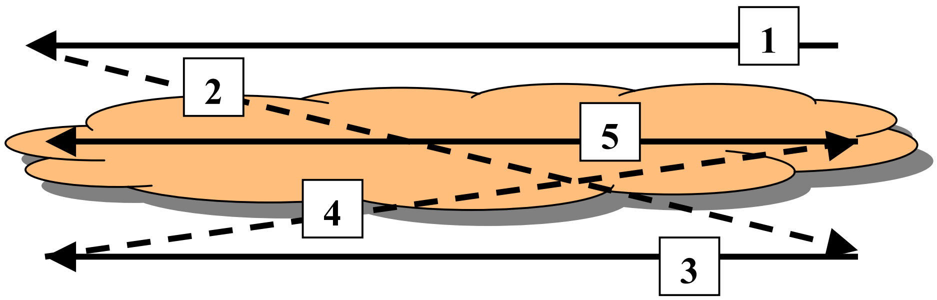


Figure E3: Flight profile for distinct aerosol layer. 1) straight and level radiation leg above layer, **2)** flat descent through layer (pitch ≥-10 deg), **3)** straight and level radiation leg below layer, **4)** flat ascent into layer (pitch≤10 deg), **5)** straight and level in situ microphysical leg.

Two extreme situations must be considered: 1) the Asian aerosol event occurs in the immediate vicinity of Monterey, or 2) the Asian aerosol event occurs at the maximum range of the Twin Otter. Actual conditions may fall somewhere in between these two extremes, and since the morphology of the Asian aerosol events could vary tremendously - from a single, thin discreet layer, to multiple-altitude layers, to an extended layer from the surface to the top of the troposphere – the flight plans and times listed below will be modified accordingly to match the aerosol situation.

CASE 1: Asian aerosols near Monterey

Total Time: 5.0 hours

1) Take-off from Monterey

2) MAARCO overflight: (Time: ≅20 mins; see Flight Plan 4 below)

3) Ferry out over the ocean: (Time: ≅ 20 mins)

Instructions:

- Ferry at high altitude ≥ 11,000 ft
- Search for clear skies, open ocean area

4) Straight and level high altitude radiation leg: (Time: ≅ 10 mins)

Instructions:

- Mark location of each endpoint

5) Level-Escalator Descent: (Time: ≅ 20-40 mins depending on initial altitude)

Instructions:

- Pitch/roll < +/- 10 degrees
- Descent rate ≤ 500 fpm
- All legs should be stacked over each other

Procedure:

- Flat descent underneath high altitude radiation leg until endpoint
- 90/270 degree turn
- Flat descent underneath high altitude radiation leg until endpoint
- 90/270 degree turn
- Continue this descent pattern until 100 ft altitude

6) Straight and level 100 ft low altitude radiation leg: (Time: ≅ 10 mins)

Instructions:

- Fly underneath high altitude radiation leg (between marked endpoints)

Procedure:

- Straight and level 10 min leg; pitch/roll ≤ 10 degrees

7) Sample above, below, and inside aerosol layers: (Time: ≅ 180 mins)

a) If distinct layers: (Time: ≥ 40 mins per layer. Total time depending on thickness and number of layers; not to exceed 180 mins)

Instructions:

- All legs should be stacked over each other

Procedure:

- Flat climb through top of individual layer at ≤ 500 fpm, pitch/roll ≤ 10 degrees
- 90/270 degree turn
- Straight and level 10 min leg directly above aerosol layer
- 90/270 degree turn
- Flat descent through layer at ≤ 500 fpm, pitch/roll ≤ 10 degrees
- 90/270 degree turn
- Straight and level 10 min leg directly below aerosol layer
- 90/270 degree turn
- Flat climb into layer at ≤ 500 fpm, pitch/roll ≤ 10 degrees
- 90/270 degree turn
- Straight and level 10 min leg inside layer. If layer is thick enough, fly multiple altitude 10 min legs inside layer.
- Proceed to next layer and repeat sampling procedure until time runs out

b) If extended layer: (Time:≤180 min; 12 legs possible, assuming ≈15min/leg)

Instructions:

- Fly this profile if aerosol layer extends throughout altitude range.
- All legs should be stacked over each other

Procedure:

- Flat climb of 1000-1500 ft at ≤ 500 fpm, pitch/roll ≤ 10 degrees
- 90/270 degree turn
- Straight and level 10 min leg
- 90/270 degree turn
- Continue flat climbs in steps of 1000-1500 ft followed by straight and level 10 min legs until top of extended aerosol layer or out of time

8) Ferry home: (Time: ≅ 20 mins)

Instructions:

- Altitude at discretion of pilots

CASE 2: Asian aerosols at maximum range of Twin Otter

Total Time: 5.0 hours

1) Take-off from Monterey

2) Transit to pre-arranged location: (Time: ≤90 mins)

Instructions:

- Altitude and speed at discretion of pilots.
- Ideally, transit at high altitude ≥ 11,000 ft

3) At site:

Instructions:

- Search for clear skies, open ocean area (ideal)

4) Straight and level high altitude radiation leg: (Time: ≅ 10 mins)

Instructions:

- Mark location of each endpoint

5) Level-Escalator Descent: (Time: ≅ 20-40 mins depending on initial altitude)

Instructions:

- Pitch/roll < +/- 10 degrees
- Descent rate ≤ 500 fpm
- All legs should be stacked over each other

Procedure:

- Flat descent underneath high altitude radiation leg until endpoint
- 90/270 degree turn
- Flat descent underneath high altitude radiation leg until endpoint
- 90/270 degree turn
- Continue this descent pattern until 100 ft altitude

6) Straight and level 100 ft low altitude radiation leg: (Time: ≅ 10 mins)

Instructions:

- Fly underneath high altitude radiation leg (between marked endpoints)

Procedure:

- Straight and level 10 min leg; pitch/roll ≤ 10 degrees

7) Sample above, below, and inside aerosol layers: (Time: ≅ 60 mins)

a) If distinct layers: (Time: ≥ 40 mins per layer. Total time depending on thickness and number of layers; not to exceed 60 mins)

Instructions:

- All legs should be stacked over each other

Procedure:

- Flat climb through top of individual layer at ≤ 500 fpm, pitch/roll ≤ 10 degrees
- 90/270 degree turn
- Straight and level 10 min leg directly above aerosol layer
- 90/270 degree turn
- Flat descent through layer at ≤ 500 fpm, pitch/roll ≤ 10 degrees
- 90/270 degree turn
- Straight and level 10 min leg directly below aerosol layer
- 90/270 degree turn
- Flat climb into layer at ≤ 500 fpm, pitch/roll ≤ 10 degrees
- 90/270 degree turn
- Straight and level 10 min leg inside layer. If layer is thick enough, fly multiple altitude 10 min legs inside layer.
- Proceed to next layer and repeat sampling procedure until time runs out

b) If extended layer: (Time:≤60 mins; 4 legs possible, assuming ≈ 15 min/leg)

Instructions:

- Fly this profile if aerosol layer extends throughout altitude range.
- All legs should be stacked over each other

Procedure:

- Flat climb of 2000-4500 ft at ≤ 500 fpm, pitch/roll ≤ 10 degrees
- 90/270 degree turn
- Straight and level 10 min leg
- 90/270 degree turn
- Continue flat climbs in steps of 2000-4500 ft followed by straight and level 10 min legs until top of extended aerosol layer or out of time

8) Ferry home: (Time: ≅ 90 mins)

Instructions:

- Altitude at discretion of pilots
- Ideally, below most of aerosol layer to get horizontal extent

FLIGHT PLAN 4: MAARCO OVERFLIGHT

Objectives: Compare aircraft measurements with surface radiometer, lidar, sun photometer, and in situ particle sampler measurements at the MAARCO site. Test lidar extinction retrieval method.

Requirements: Clear to partly cloudy skies over MAARCO. Asian dust event over surface site (ideal).

Strategy: A vertical profile over the MAARCO surface site will be flown. The Twin Otter must fuel at the Monterey County Airport prior to each flight. Since MAARCO is immediately adjacent to the airport numerous opportunities will exist to perform surface/airborne comparisons.

Total Time: ≅ 25 min.

1) Flat-Escalator Climb:

Instructions:

- Leg lengths ≅ 5 miles; +/- 2.5 miles each side of MAARCO

Procedure:

- Take-off from Monterey
- Climb to a minimum altitude (less than 1000 ft) with pitch < 10 degrees
- Turn and overfly MAARCO straight and level at minimum altitude
- Turn, climb and overfly MAARCO at <500 fpm, pitch < 10 degrees
- Turn, climb and overfly MAARCO at <500 fpm, pitch < 10 degrees

...continue until reaching altitude > 11,000 ft

- Straight and level overfly of MAARCO at 11,000 ft (to measure AOT above aircraft).

FLIGHT PLAN 5: MIRA OVERFLIGHT

Objectives: Compare aircraft measurements with surface MicroTops handheld sun photometer, and in situ DRUM sampler measurements at the MIRA site.

Requirements: Clear to partly cloudy skies over MIRA. An Asian dust event over MIRA (ideal).

Strategy: A vertical profile over the MIRA surface site will be flown.

Total Time: ≅ 25 min.

1) Escalator Climb:

Instructions:

- Leg length ≅ 5 miles; +/- 2.5 miles each side of MIRA

Procedure:

- Take-off from Monterey
- Climb to 5500 ft
- Turn and overfly MIRA straight and level at 5500 ft, NW-SE direction
- Turn, climb and overfly MIRA at <500 fpm, pitch < 10 degrees
- Turn, climb and overfly MIRA at <500 fpm, pitch < 10 degrees

...continue until reaching altitude > 11,000 ft

- Straight and level overfly of MIRA at 11,000 ft (to measure AOT above aircraft).

FLIGHT PLAN 6: RV PT SUR OVERFLT/OCEAN COLOR VALIDATION

Objectives: a) To characterize the atmospheric aerosols above the R/V Pt Sur for use in validation studies of ocean color retrievals from the ship and the SeaWifs satellite. b) To compare measurements from the Twin Otter hyperspectral imager (PHILLS) with shipboard measurements. c) To compare aircraft AOT measurements with shipboard MicroTops handheld sun photometer measurements.

Requirements: Clear skies over the ship and open ocean. An Asian dust event over the R/V Pt Sur (ideal). For the PHILLS comparison leg there should be no clouds between the aircraft and the ship.

Strategy: Fly ascents and descents and multiple altitude level legs over the R/V Pt Sur from low altitude (100 ft) to high altitude (11,000 – 17,500 ft) to fully characterize the aerosol conditions above the ship.

This is the same strategy as Flight Plan 3 "Asian Aerosol Characterization" with the additional requirement of at least one straight and level 10 min leg at 5000 ft for the PHILLS hyperspectral imager. We will also try to coordinate this flight with overpasses of the SeaWifs satellite.

Total Time: ≅ 5 hours

1) Take-off from Monterey

2) Transit to R/V Pt Sur location (Time ≅ 30 min.)

3) Fly Flight Plan 3 "Asian Aerosol Characterization", Case 1 "Asian aerosols near Monterey (see description above) (Time ≅ 240 min.)

4) Straight and level leg at 5000 ft:

Instructions:

- Should occur at least once during flight

Procedure:

- Straight and level overfly of R/V Pt Sur at 5,000 ft

FLIGHT PLAN 7: SATELLITE AOT COMPARISONS

Objectives: To characterize the atmospheric aerosols for use in comparison/validation studies of aerosol optical thickness retrievals from satellites (SeaWifs, MODIS, AVHRR, GOES).

Requirements: Clear skies and open ocean. An Asian dust event (ideal).

Strategy: Fly ascents and descents and multiple altitude level legs from low altitude (100 ft) to high altitude (11,000 – 17,500 ft) to fully characterize the column aerosol conditions. These flights will be coordinated with the overpass times of the relevant satellite. Ideally, a total column vertical ascent or descent, centered on the time of the satellite overpass will be performed.

This is the same strategy as Flight Plan 3 "Asian Aerosol Characterization" with the additional requirement of timing the total column ascent or descent to the satellite overpass time.

Total Time: ≅ 5 hours

1) Take-off from Monterey

2) Transit to best location for satellite overpass (Time ≅ 30 min.)

Instructions:

- Want a clear sky, open ocean location of sufficient area to fly 10 min straight and level legs

3) Fly Flight Plan 3 "Asian Aerosol Characterization", Case 1 "Asian aerosols near Monterey (see description above) (Time ≅ 240 min.)

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